U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-260 215

REMOVAL OF ORGANICS BY ACTIVATED CARBON

ROBERT A. TAFT SANITARY ENGINEERING CENTER
CINCINNATI, OHIO

AUGUST 1968

002217 253064

PB 260 215

REMOVAL OF ORGANICS BY ACTIVATED CARBON

By

Arthur N. Masse

U. S. Department of the Interior
Federal Water Pollution Control Administration
Cincinnati Water Research Laboratory
Cincinnati, Ohio 45226

August 1968

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

00217 253064

PB 260 215

REMOVAL OF ORGANICS BY ACTIVATED CARBON

By

Arthur N. Masse

U. S. Department of the Interior
Federal Water Pollution Control Administration
Cincinnati Water Research Laboratory
Cincinnati, Ohio 45226

August 1968

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

BIBLIOGRAPHIC DATA SHEET	1. Report No.	2.	3. Recipient's Accession No. PB-260 215
4. Title and Subtitle Removal of Organics by Activated Carbon			5. Report Date Aug 68 6.
7. Author(s) Arthur N. Masse			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio. Cincinnati Water Research Lab.			10. Project/Task/Work Unit No. 11. Contract/Grant No.
12. Sponsoring Organization Name and Address			13. Type of Report & Period Covered 14.

15. Supplementary Notes

16. Abstracts

Granular and powdered activated carbons are receiving increasing attention as a means for removing dissolved BOD and COD from municipal wastewater. Pilot plants utilizing both materials for removing organic materials from secondary effluent are described. Interest is now high in the use of activated carbon as a substitute for the activated sludge process. Indications are that the cost of powdered carbon adsorption processes will be very close to that of granular carbon. Powdered carbon plants will probably entail a smaller initial investment and may have application where the need for carbon is sporadic.

17. Key Words and Document Analysis. 17a. Descriptors

17b. Identifiers/Open-Ended Terms

*Carbon
Industrial plants
*Waste water treatment
Organic wastes
Water pollution control
Oxygen sag
Municipalities
Sewage treatment
Cost effectiveness

17c. COSATI Field/Group 13B

18. Availability Statement	19. Security Class (This Report) UNCLASSIFIED	21. No. of Pages 35
	20. Security Class (This Page UNCLASSIFIED	22. Price

REMOVAL OF ORGANICS BY ACTIVATED CARBON

ABSTRACT

Granular and powdered activated carbons are receiving increasing attention as a means for removing dissolved BOD and COD from municipal wastewater. Pilot plants utilizing both materials for removing organic materials from secondary effluent have been on stream for several years and a 7.5 mgd process using granular carbon is being started up. Interest is now high in the use of activated carbon as a substitute for the activated sludge process and several studies along these lines are planned.

The rate of adsorption on activated carbon is significantly affected by the particle size of the carbon but this size seems to have little effect on the ultimate capacity for adsorption. Total pore area and pore size distribution appear to be the controlling factors affecting the carbon's capacity for adsorbing organic materials. A wide pore size distribution is desirable for adsorbing the wide range of materials present in wastewater. A mixture of carbons may be necessary to provide the optimum pore size distribution.

Adsorption on granular carbon, at the 10 mgd range, can be accomplished for about 8¢/1,000 gallons. A significant reduction in this cost may be possible by changes in the system configuration, size of carbon, regeneration technique, rate of application and residence time required.

Indications are that the cost of powdered carbon adsorption processes will be very close to that of granular carbon. Powdered carbon plants will probably entail a smaller initial investment and may have application where the need for carbon is sporadic.

REMOVAL OF ORGANICS BY ACTIVATED CARBON*

By

Arthur N. Masse**

INTRODUCTION

It has become obvious that the biological waste treatment processes do not, and probably cannot, remove all of the organic compounds from wastewater, even from one that is completely domestic in origin. Although the necessity for removing these organics is not imminent in all parts of the country, many water-scarce areas are already looking ahead to the reuse of wastewater for beneficial purposes. This reuse will make improved removal of organic materials necessary. As our population and water consumption increase, more and more of our cities will find it necessary to turn to renovated wastewater as the most economical source of new supply.

Adsorption on activated carbons, both granular and powdered, has been investigated extensively in recent years because of carbon's ability to adsorb organic materials from wastewater. Research is continuing and several pilot- and full-scale installations are presently on stream while others are being designed.

CHARACTERISTICS OF ACTIVATED CARBON

Activated carbons vary widely in their pore structure, surface area, density, particle size, cost and method of production. They are also derived from several different raw material sources.

---

* Presented at the 156th National ACS Meeting, Atlantic City, New Jersey, September 8-13, 1968.

**Acting Chief, Pilot Plant Research, Advanced Waste Treatment Branch, Research & Development, FWPCA, Cincinnati Water Research Laboratory, Cincinnati, Ohio 45226.

Properties of carbon that are of prime importance in an adsorption operation include total surface area and pore size distribution. It is the total area which determines the capacity of a carbon for adsorption and it is the pore size distribution which determines the accessibility of the surface area to specific adsorbate molecules.

A relatively small percent of an activated carbon's total surface area is on the external surface of the particle. Reducing the particle size from 1 mm to 10 microns increases the carbon's total surface area only slightly. Size reduction does, however, significantly reduce the average distance between the external surface that is immediately available to the adsorbate and the internal pore surface area. This reduces the distance through which an adsorbate molecule must diffuse to reach the internal area and thus, the most important effect of particle size reduction is a decrease in time necessary to reach adsorption equilibrium (that is, an increase in the rate of adsorption). Figure 1 (Morris and Weber, 1964) is a plot of the effect of particle size on rate of adsorption.

Total surface area is normally measured by the desorption of nitrogen gas. Of equal importance is the distribution of this area into pores of different diameters. This can be measured by determining the amount of nitrogen desorbed at intermediate pressures.

Another method for determining pore size distribution of a given carbon is by measuring the amount of adsorbate of a given molecular size that is removed from solution. For example, the amount of iodine adsorbed from solution has been found to be proportional to the surface area contributed by pores having diameters greater than 10 angstroms. Similarly, the adsorption of methylene blue and molasses can be correlated with surface area in pores with diameters greater than 15 and 28 angstroms, respectively.

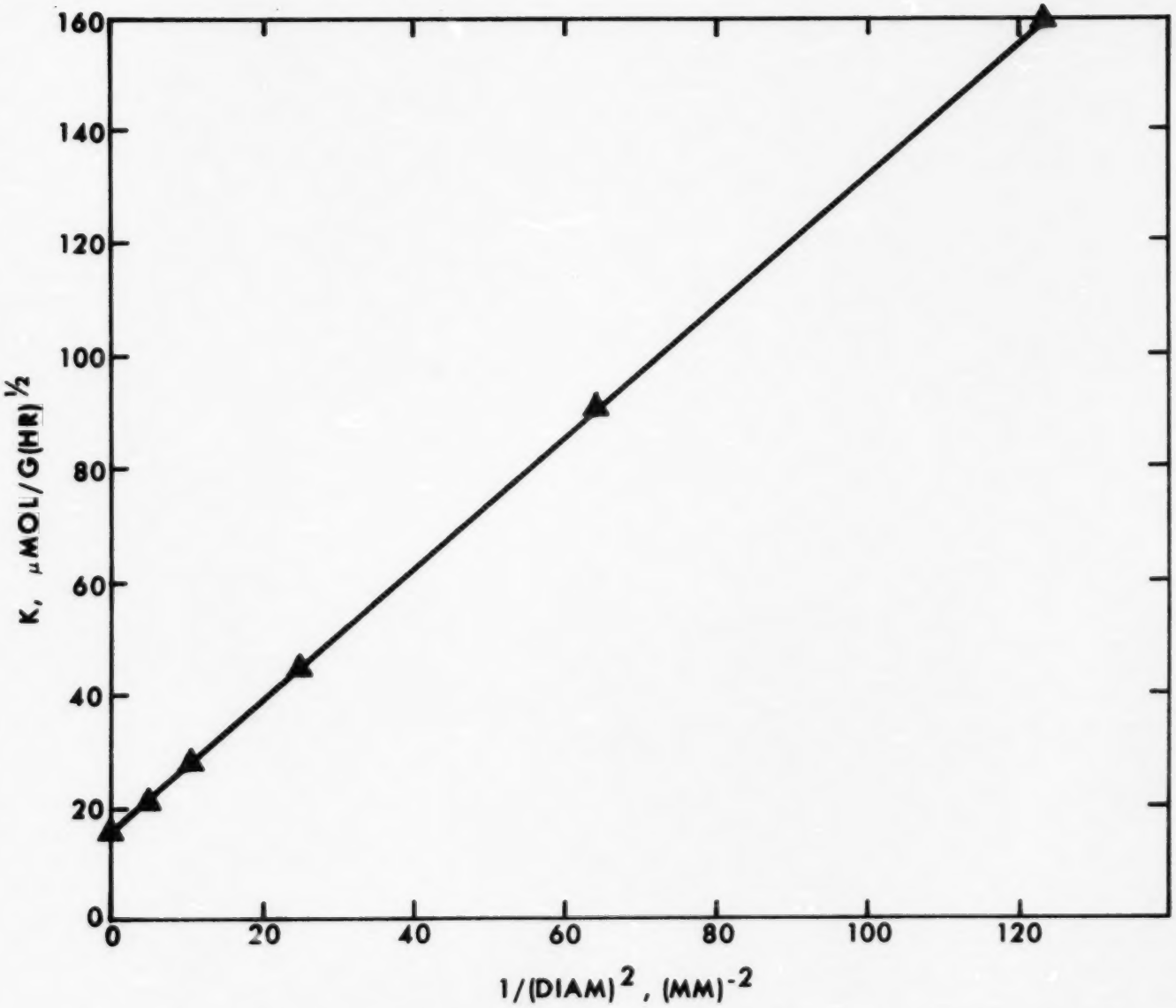

FIGURE 1 - THE EFFECT OF PARTICLE SIZE ON RATE OF ADSORPTION BY COLUMBIA CARBON
(25°C, C_o=13.9 μM [3-DODECYL] BENZENESULFONATE).

APPLICATION OF GRANULAR ACTIVATED CARBON

The method of application of the activated carbon to the wastewater is determined primarily by the particle size of the carbon to be used. In practice, activated carbons are referred to as either granular or powdered. The granular carbon of current interest in wastewater renovation ranges in mesh size from 8x30 to 16x40, that is, between 0.5 and 2 mm in diameter.

The granular carbons are customarily used in a columnar configuration. The wastewater can be applied upflow or downflow through the carbon. The carbon can be static or can be moved either continuously or in slugs countercurrent to the water flow.

Figure 2 (Parkhurst, Dryden, et al., 1967) is a schematic of the fixed-bed, downflow configuration that is used at the Pomona, California pilot plant where the Federal Water Pollution Control Administration (FWPCA) of the U. S. Department of the Interior has been conducting a study in cooperation with the Los Angeles County Sanitation Districts. The unfiltered wastewater flows through four contactors in series. When the organic carbon content of the product from the last contactor in series reaches a given value, the carbon in the first contactor is regenerated and placed last in the series. We thus have a semi-continuous countercurrent operation.

The South Tahoe (California) Public Utility District is operating a 7.5 mgd granular carbon plant to protect the waters of Lake Tahoe. In this plant, the contactors are operated in parallel. The wastewater is introduced upflow and the carbon is removed in slugs from the bottom of the columns. About 20% of the carbon charge is removed at a time. These columns are completely filled with carbon so there is little, if any, expansion during operation. Figure 3 (Smith and Chapman, 1967) is a schematic of the Lake Tahoe activated carbon wastewater treatment plant.

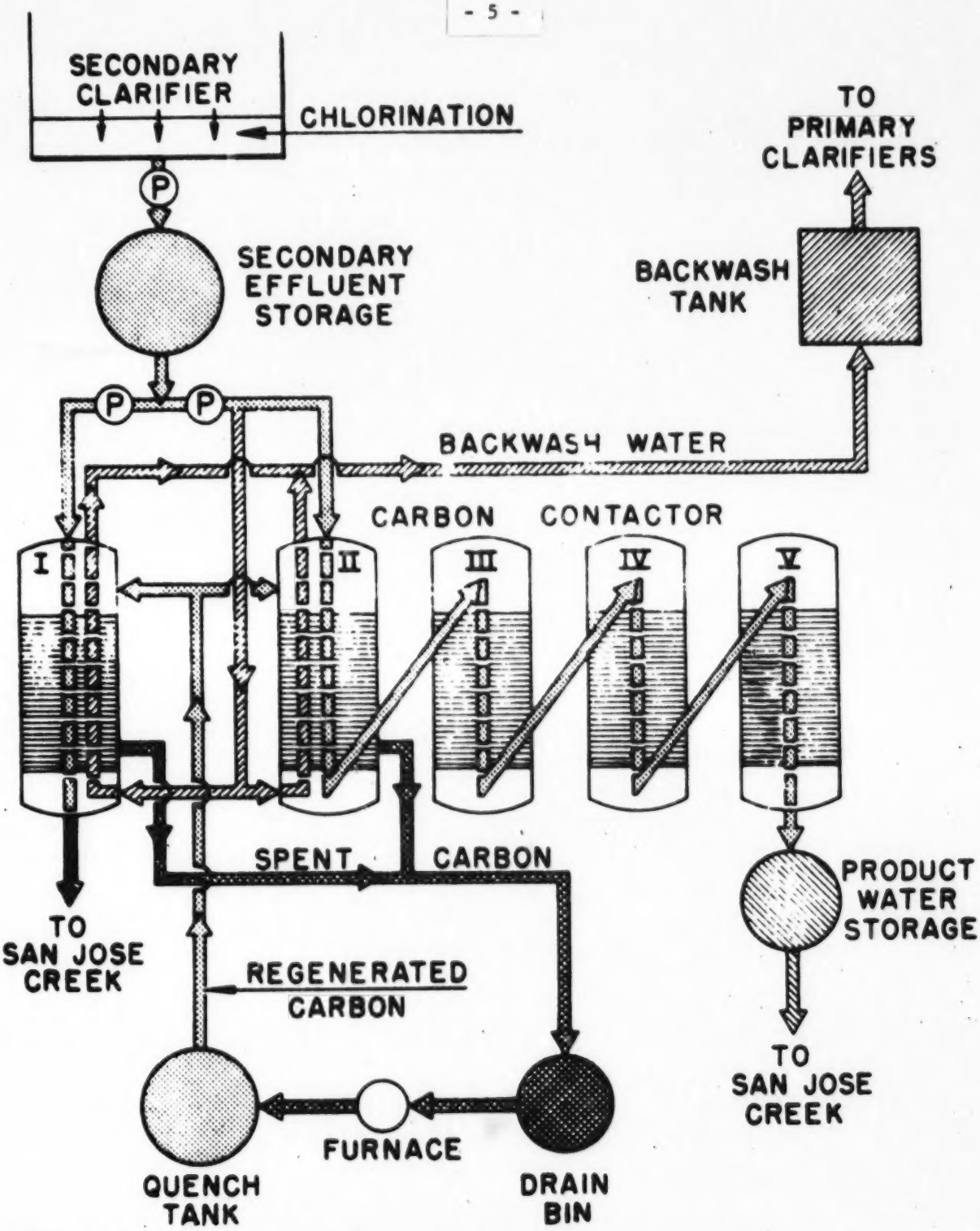

FIGURE 2

CARBON ADSORPTION PILOT PLANT

POMONA, CALIFORNIA

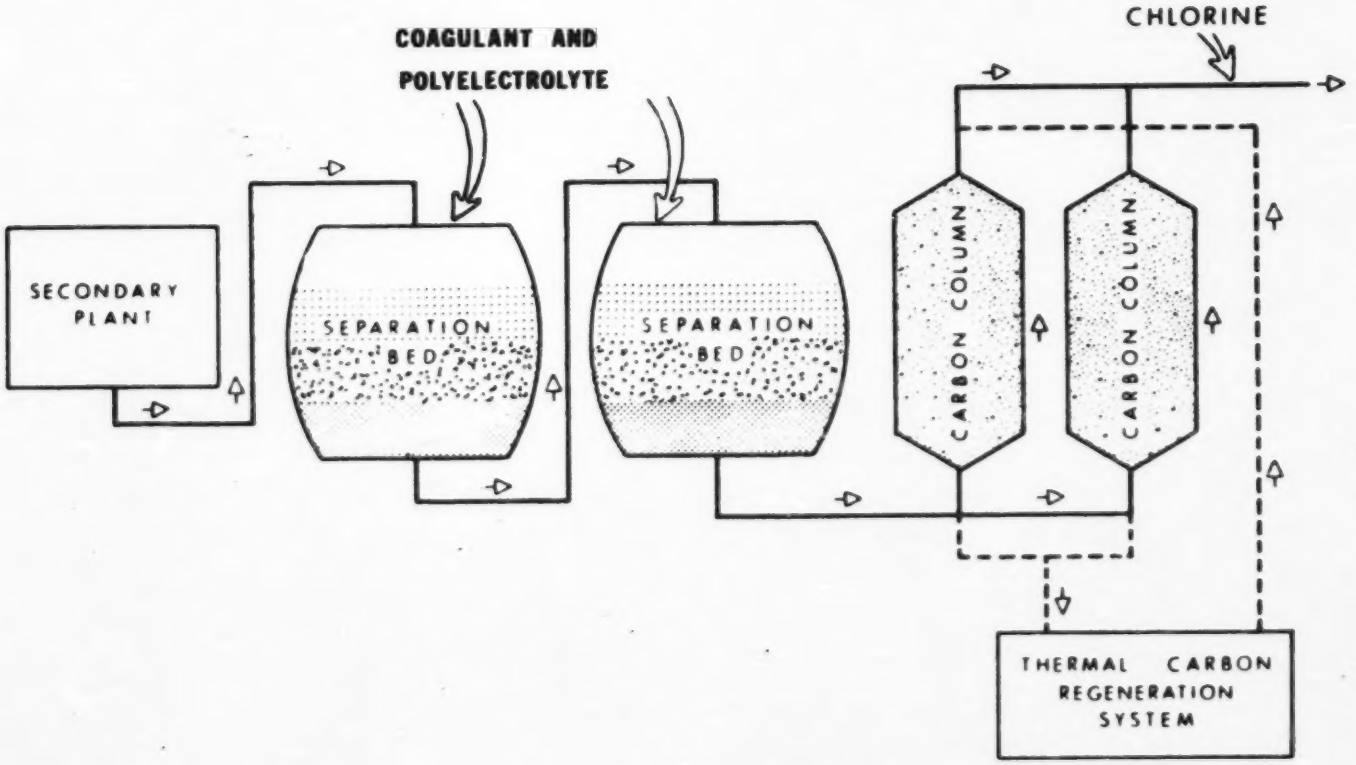

FIGURE 3 - CARBON ADSORPTION PILOT PLANT, LAKE TAHOE, CALIFORNIA

Use of the fluidized or expanded bed of activated carbon has been investigated in recent years. In this configuration, the wastewater is introduced upflow in a column only partially filled with carbon. This configuration allows operation without the pressure-drop increase experienced in the downflow system. It also permits the use of a finer mesh carbon which, in theory, should reduce the contact time necessary. In practice, however, the particle size is limited to that which will not be washed out of the column at reasonable flow rates (about 40 mesh). Referring to Figure 1, the abscissa for an 8x30 mesh carbon would be 1.39, while that for a 12x40 carbon would be 2.78. These give essentially the same rate constant. As a result, little difference in adsorption rate could be expected. Columnar studies have confirmed that the size of particle in a column has little effect on adsorption rate.

Still another configuration of interest is the use of multiple columns, either upflow or downflow, in parallel. This system can be used when a high degree of organic removal is not necessary. Start-up of the columns is staggered so that, when one column is nearing exhaustion, another is being started up on freshly-regenerated carbon and the other columns are at intermediate stages of exhaustion. The blended product from the columns would meet the desired quality specifications.

The choice of type of configuration is, of course, a matter of economic optimization taking both capital and operating costs into account. With a clarified feed, all configurations should produce the same quality water if the contact times are equal. With a feed containing suspended solids, the packed beds, either upflow or downflow, have the added advantage of a filtering operation. Excessive suspended solids in the feed can, of course, make operation of a packed bed impractical.

Most of the experience at the FWPCA's Cincinnati Water Research Laboratory has been with the downflow, multiple column, fixed bed configuration. Following preliminary laboratory (Morris and Weber, 1964 and 1966) and bench-scale (Joyce and Sukenik, 1964 and 1965) studies, a 200 gpm carbon adsorption pilot plant was designed for operation at the Pomona Water Pollution Control Plant (Figure 2). This plant has been in operation continuously since June 1965 using unfiltered secondary effluent from an activated sludge plant as the feed water.

Figure 4 (Summary Report, 1968) is a photograph of the system, including the regeneration furnace. The wastewater application rate at Pomona is 7 gpm/ft^2 and the depth of carbon in each contactor is 9.5 ft. for a total contact time of 38 minutes, based on an empty column. The carbon has a porosity of about 50% so the actual contact time is 19 minutes. Table I (Parkhurst, Dryden, et al., 1967) shows the feed and product water quality at this installation. Note the excellent color removal obtained. The nitrate removal shown in this table has significance. The mechanism of removal is evidently the nitrate ion acting as an oxygen donor to anaerobic bacteria. This phenomenon can be enhanced by the addition of a biodegradable material (methanol) to obtain essentially complete removal of the nitrate ion. In this case, the activated carbon acts only as a medium on which the anaerobic bacteria grow and tests have shown that it has no advantage over sand.

With a given carbon and a specific wastewater, the product quality is a function of the contact time and the amount of wastewater that has been passed through the column. Figure 5 (Summary Report, 1968) illustrates that, in the range considered, the adsorption rate is independent of water velocity.

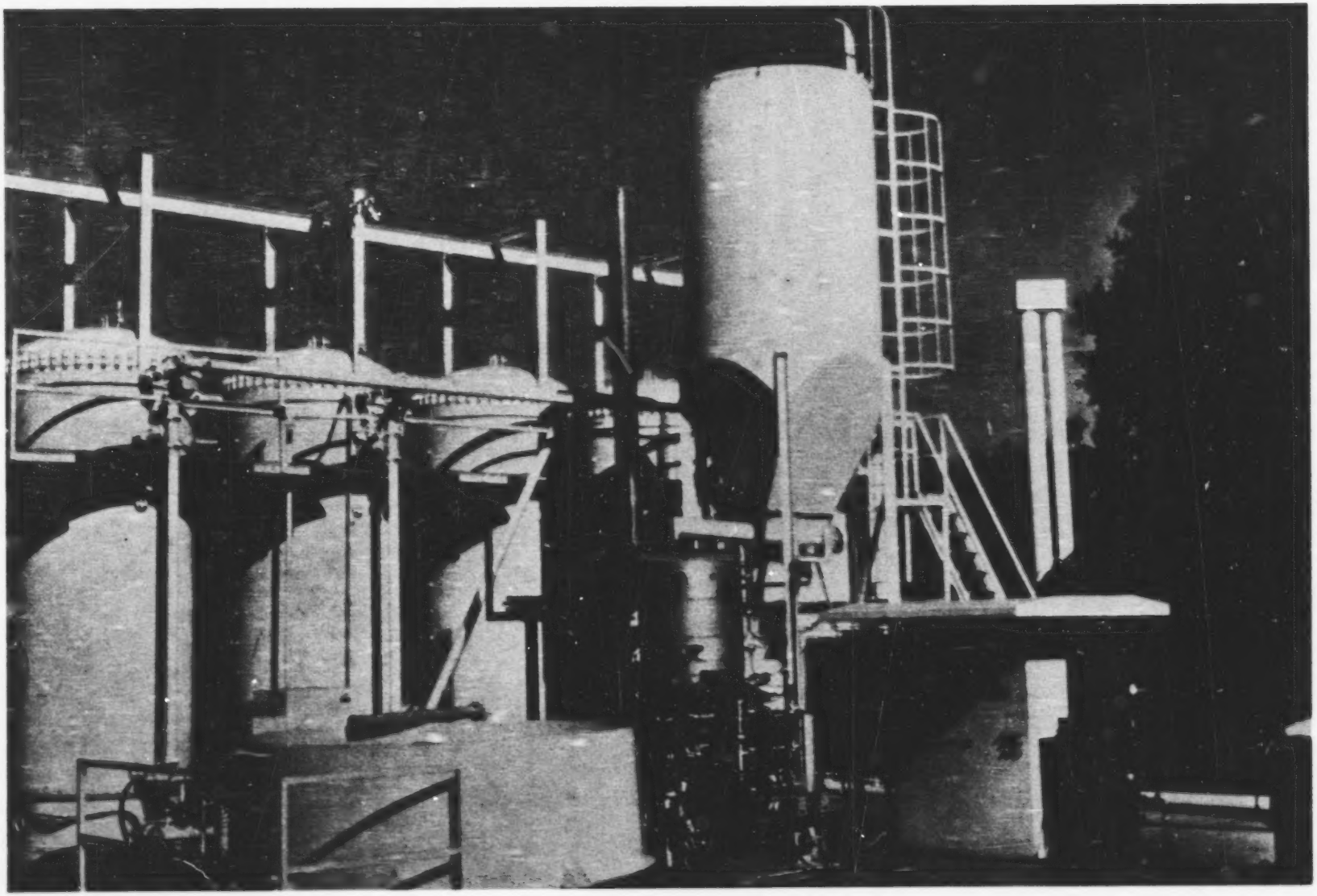

FIGURE 4 - 200 GPM GRANULAR ACTIVATED CARBON PILOT PLANT, POMONA, CALIFORNIA.

TABLE I

Effect of Treatment of Secondary Effluent
by Activated Carbon Adsorption

Pomona, California - June, 1965 - August, 1966

	Carbon Column Influent	Carbon Column Effluent
Suspended Solids, mg/l	10	< 1
Chemical Oxygen Demand (COD), Total, mg/l	47	9.5
COD, Dissolved, mg/l	31	7
Nitrate as N	6.7	3.7
Turbidity, JTU	10.3	1.6
Color	30	3
Threshold Odor	12	1
Carbon Chloroform Extract, mg/l	-	0.014

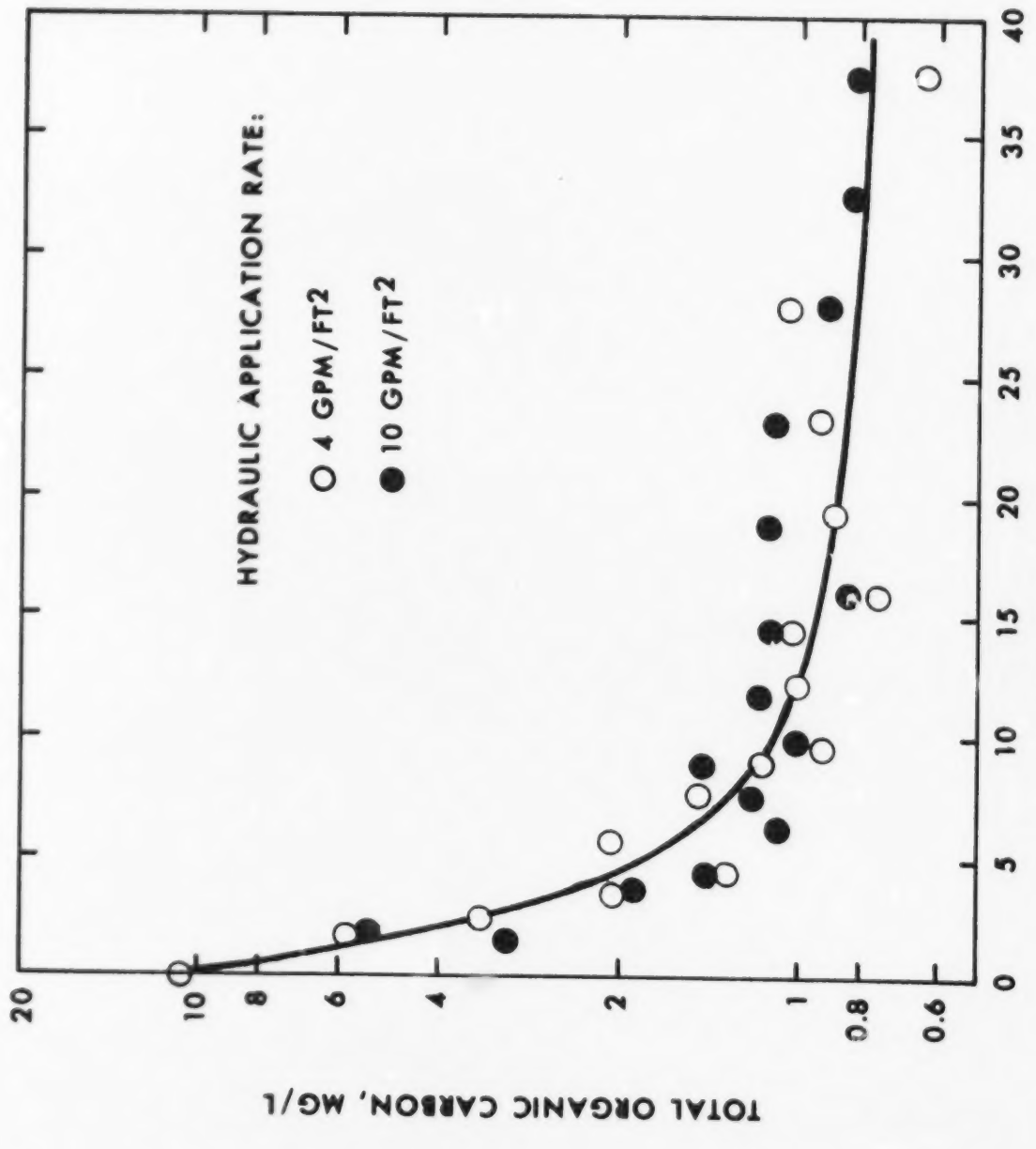

FIGURE 5 - EFFECT OF FEED RATE ON CARBON COLUMN PERFORMANCE.

At Pomona, California, regeneration was initially at the rate of 250 lb of carbon per million gallons processed to maintain the desired water quality. Because restoration of the carbon to its initial capacity by regeneration is not yet feasible, this figure is increasing and it is expected to level off at a regeneration rate of about 400 lb per million gallons. At the present "loss on regeneration" rate of 7%, the make-up of fresh carbon would be 28 lb/million gallons.

The characteristics of the activated carbon are, of course, a most important consideration. In the absence of a laboratory test to evaluate a carbon for this application, a number of small-diameter columns in parallel were packed with granular activated carbons from the major carbon manufacturers. The columns were run continuously on secondary effluent. Table II presents data after 5300 bed volumes of secondary effluent had been passed through the carbon. Four of the six carbons tested were similar in adsorption capacity (at the 38-minute contact time) on a weight basis. The other two carbons were less efficient in this application. In a continuation of this test, the carbons from Atlas, Calgon, and West Virginia Pulp & Paper Company are being regenerated and will be returned to service in Pomona.

Another important consideration is the physical stability of a carbon in this service. The carbons from Atlas, Calgon, and West Virginia have been backwashed continuously for over 200 hours in small columns at Pomona and no increase in pressure drop has occurred through the columns in downflow operation.

At Nitro, West Virginia, granular activated carbon has been used to combat the severe problem in taste and odor that the city had been experiencing in its drinking water source. To accomplish this treatment,

TABLE II*

Carbon Comparison Study
Pomona, California

Manufacturer	Mesh Size	Iodine Number	Apparent Density-gm/ml	Adsorption Capacity lb. Dissolved COD/100 lb. carbon Contact Time, Minutes 18 (5 ft.)	38 (10 ft.)
American Norit Co.	8 x 20	633	0.327	4.6	6.9
Witco Chemical Co. (Grade 718)	18 x 40	1178	0.509	13.2	8.3
Atlas Chemical Industries	12 x 40	573	0.408	22.6	17.7
West Virginia Pulp & Paper Co. Nuchar WV-L	8 x 30	1073	0.504	27.4	18.9
Calgon Corp. Filtrasorb 300	8 x 30	898	0.510	18.9	18.7
Calgon Corp. Filtrasorb 400	12 x 40	997	0.482	32.0	21.7

*Mention of specific proprietary equipment or products throughout this paper is for information purposes only and does not constitute endorsement by the Federal Water Pollution Control Administration and the U. S. Department of the Interior.

Nitro replaced the sand in their filter beds with granular activated carbon. With a contact time of 5 to 10 minutes, the activated carbon reduces the threshold odor to acceptable levels from the 300 to 2000 levels experienced throughout the year in the Kanawha River.

APPLICATION OF POWDERED ACTIVATED CARBON

The powdered carbon most thoroughly evaluated for reducing the residual organic carbon content of wastewater is Aqua Nuchar, produced by the West Virginia Pulp & Paper Company. This carbon has a median particle size of about 10 microns. Referring again to Figure 1, the abscissa for this carbon would be 10,000. Though not on the scale, this carbon obviously would exhibit a significant increase in the rate of adsorption over the rate with granular carbons. Laboratory tests have shown that a powdered carbon adsorbs over 90% of its equilibrium capacity in less than 5 minutes.

The Dorr-Oliver Company, under contract to the Federal Water Pollution Control Administration, developed a powdered activated carbon process for removing refractory organic materials from wastewater. Davies and Kaplan (1964) have reported the results of this study. The recommended contacting system was a two-stage, countercurrent, mixer-settler operation as illustrated in Figure 6 (Summary Report, 1968). In this arrangement, the feed water is contacted in the first stage with a partially-spent carbon. After 7 minutes of rapid mixing, a cationic polymer is added and the mixture is allowed to flocculate with gentle mixing for 15 minutes. The final step in the first stage is settling in a one-hour residence tank at an overflow rate of 1-1/4 gpm/ft^2. The water then flows to the second stage where it is contacted with virgin carbon in an identical series of steps. After the second-stage settling, the water flows through a dual-media filter for removal of the powdered carbon not removed by settling.

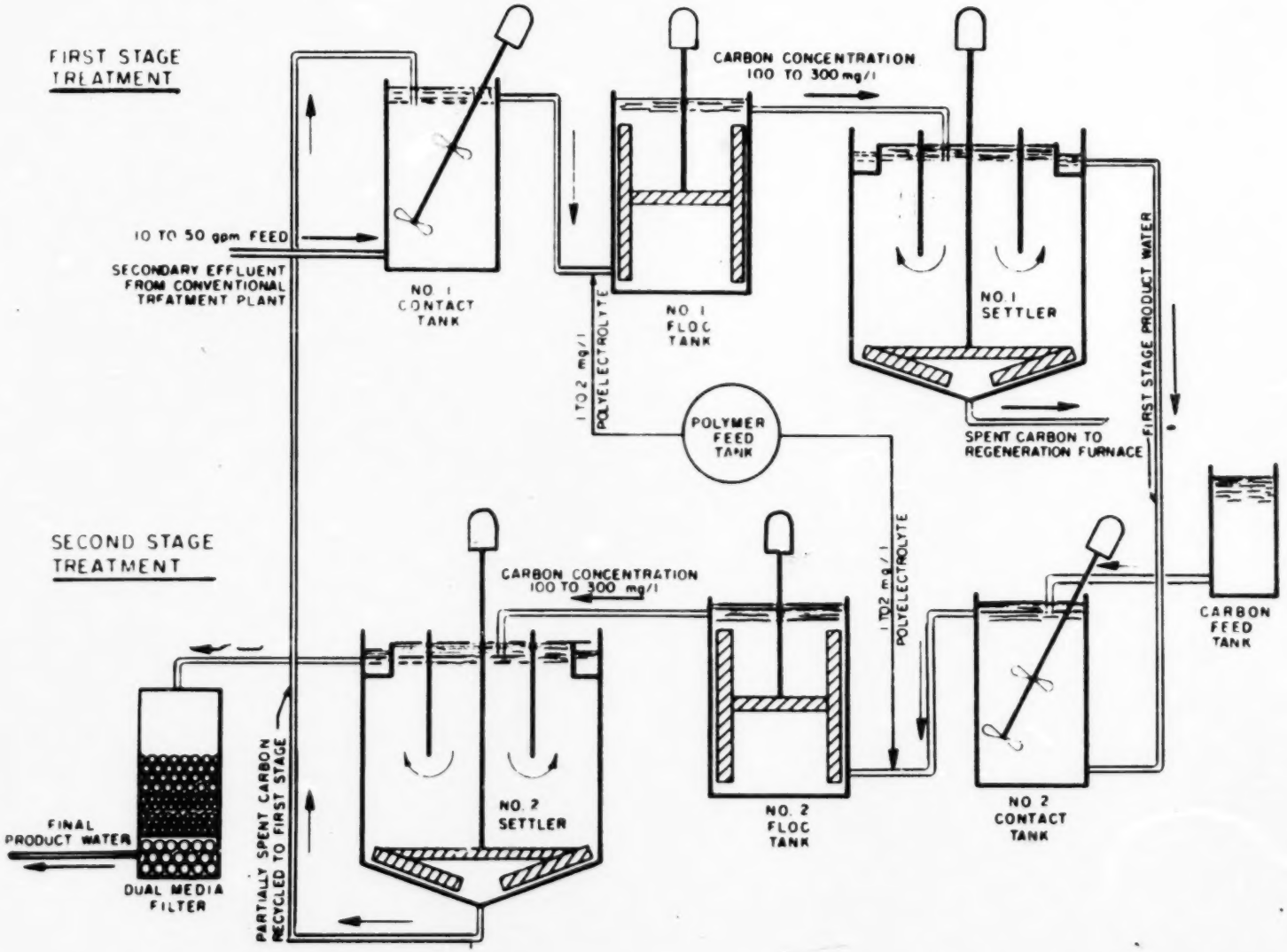
FIRST STAGE TREATMENT
10 TO 50 gpm FEED
SECONDARY EFFLUENT FROM CONVENTIONAL TREATMENT PLANT
NO. 1 CONTACT TANK
NO. 1 FLOC TANK
CARBON CONCENTRATION 100 TO 300 mg/l
1 TO 2 mg/l POLYELECTROLYTE
POLYMER FEED TANK
NO. 1 SETTLER
SPENT CARBON TO REGENERATION FURNACE
FIRST STAGE PRODUCT WATER
SECOND STAGE TREATMENT
CARBON CONCENTRATION 100 TO 300 mg/l
1 TO 2 mg/l POLYELECTROLYTE
CARBON FEED TANK
NO. 2 SETTLER
NO. 2 FLOC TANK
NO. 2 CONTACT TANK
FINAL PRODUCT WATER
DUAL MEDIA FILTER
PARTIALLY SPENT CARBON RECYCLED TO FIRST STAGE

FIGURE 6 - POWDERED CARBON ADSORPTION PILOT PLANT, LEBANON, OHIO

The partially-spent carbon settled out in the second stage is pumped to the first stage rapid mix tank. The spent carbon settled out in the first stage is, presently, sent to waste but studies are nearing completion on methods of regeneration.

Following the preliminary laboratory work by Dorr-Oliver, a 10 gpm pilot plant was constructed and operated at the Lebanon, Ohio, Sewage Treatment Plant by FWPCA personnel. Figure 7 presents the significant results of this study. With Lebanon secondary effluent, 200 mg/l of powdered carbon was sufficient to reduce the organic carbon content to about 2 mg/l.

Several different powdered carbon-polymer combinations have been investigated in the laboratory and in the pilot plant. It has become apparent that the choice of carbon and polymer will have to be tailored to the specific application.

The Infilco Corporation evaluated the use of powdered carbon in a pilot plant (Beebe & Stevens, 1967) at the Tucson Municipal Sewage Treatment Plant. The equipment used was an Accelator recirculating slurry contact treatment unit with a nominal capacity of 5 gpm. Isotherm data indicated that this unit accomplished the equivalent of two equilibrium countercurrent contacting steps in one tank. The feed COD of 36 mg/l was reduced to 14 mg/l (after filtration) with a carbon dosage of 138 mg/l. The carbon was flocculated by adding 15 mg/l ferric sulfate to the primary mixing zone and 0.5 mg/l of Purifloc C-31 to the coagulating zone. The Infilco Company, under contract to the FWPCA, is investigating a two-stage countercurrent contacting system using Accelator-type equipment at a 20 gpm scale.

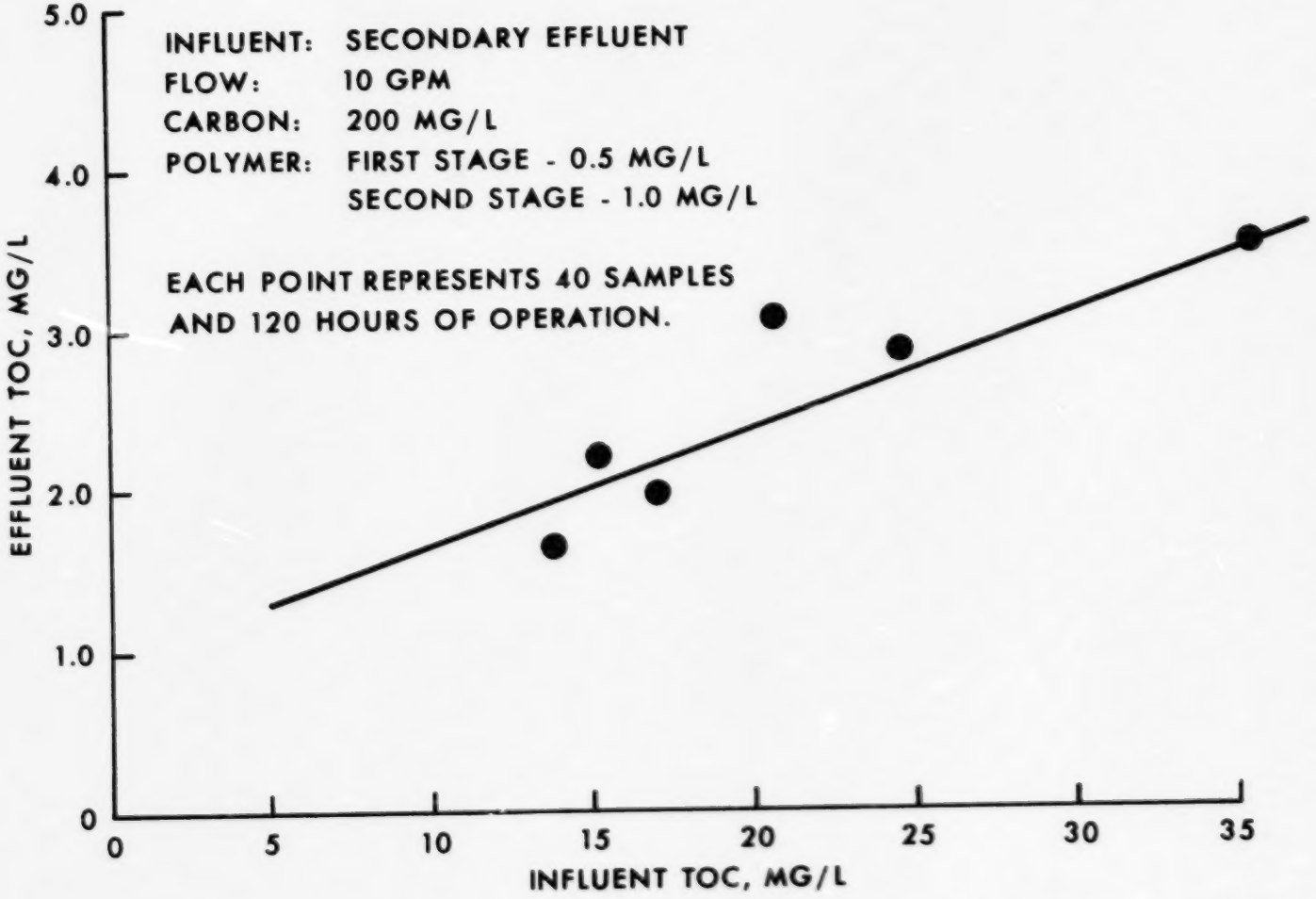

FIGURE 7 - POWDERED CARBON TREATMENT OF SECONDARY EFFLUENT
LEBANON, OHIO

ACTIVATED CARBON AS A SUBSTITUTE FOR THE BIOLOGICAL PROCESS

The Calgon Corporation announced some time ago that it had developed a process, using granular activated carbon, as a possible replacement for biological oxidation. The process uses chemicals, either organic or inorganic, to enhance the removal of suspended matter in the primary treatment of municipal wastes. This clarified wastewater is then passed through a column containing granular activated carbon.

The clarification process has been investigated full-scale with the expected increase in suspended solids removal. The carbon adsorption step has been investigated on small diameter columns. The results of one such study are shown in Table III (Rizzo, 1968). The carbon adsorption process, in this case, produced an effluent lower in suspended solids, BOD and organic carbon than that produced by all but the best of activated sludge plants.

The carbon adsorption process, as a secondary treatment step, has some potential advantages over the biological processes. Calgon claims (Rizzo, 1968) that the land required for a conventional biological treatment process is approximately 10 times that required for a clarification-carbon process. They also report that the capital cost for a conventional plant is 30 to 40% greater than that for the clarification-carbon process. In addition, the activated carbon process should be less influenced by shock loads, poisoning and low temperatures than are the biological processes. The carbon plant will be easier to operate than an activated sludge plant and operating conditions can be easily changed to meet varying influent quality and flow changes. Odor problems will be reduced with the carbon process and a benefit that may prove a major advantage will be the reduction

TABLE III

(Rizzo, 1968)

Rocky River Waste Treatment Plant
Clarification/Carbon Process

	Raw Water	Clarified Water	Carbon Contact Time, Minutes				Percent Removed
			4.7	14	23.4	32.6	
Suspended Solids, mg/l	107	65	31	13	15	7	93.3
BOD, mg/l	118	57	27	21	11	8	93.3
COD, mg/l	235	177	117	67	50	44	81.3
TOC, mg/l	52	53	33	18	15	13	75

in volume of sludge produced. A conventional 10 mgd waste treatment plant will produce about 150,000 gpd of sludge that must be treated. Approximately 70% (105,000 gpd) of this sludge is a result of secondary treatment. Substitution of carbon treatment for activated sludge treatment would probably not reduce the sludge output to 45,000 gpd because of the improved solids removal in the primary step and the solids captured and formed on the carbon. There could well be, however, a reduction of 50% in the overall volume of sludge produced.

The activated carbon process, unfortunately, cannot accomplish everything that a biological process can. The activated sludge process can be run to oxidize ammonia to the nitrate ion, thus reducing the oxygen demand on the receiving stream. Activated carbon should remove that part of the nitrogen tied up in organic compounds but the ammonia will pass through unaffected. A properly-run activated sludge process will also remove a significant fraction of the phosphorus entering the plant - this will pass through the carbon unaffected.

The City of Rocky River, Ohio, a Cleveland suburb, was directed by the Ohio Department of Health to upgrade its effluent from a 70% suspended solids removal to the quality obtainable by secondary treatment. Because of geographical considerations, Rocky River could not install conventional secondary treatment without condemnation proceedings against some of the surrounding high-quality residential properties. Potential odor problems with conventional treatment were also a factor to be considered.

Rocky River, after a study of alternatives, applied to the FWPCA for partial support of construction and operation of a clarification-carbon

process at its treatment plant. The objective is to reduce the BOD to 15 ppm and the suspended solids to 10 ppm. The data shown in Table III indicate that these standards can be met.

A preliminary design for a 10 mgd plant to be installed at Rocky River has been made. The plan calls for eight 16-ft-diameter contactors in parallel, each containing 15 ft of carbon. The contact time at the design flow will be 26 minutes. As the blended product from the eight contactors reaches the upper limit of the specifications, the carbon from the contactor which has been on stream the longest will be removed from service and regenerated. The carbon regeneration rate is expected to be between 300 and 500 lb/million gallons and the loss on regeneration is predicted to be no more than 5%.

The 10-gpm powdered carbon pilot plant at Lebanon has also been operated on primary effluent. Time available for this study was limited, so most of the data were accumulated when the plant was being operated at conditions similar to those used when treating secondary effluent. Table IV presents a summary of the feed and product quality parameters during several runs. The final effluent from the powdered carbon plant was at all times less turbid and lower in organic carbon than the effluent produced by the activated sludge plant operating on the same primary-treated wastewater. Here again, however, ammonia and phosphorus removal are not accomplished in the carbon adsorption process. Separation of the powdered carbon from the water seems more difficult with primary than with secondary effluent, but there is a good chance that this problem can be solved.

REGENERATION OF ACTIVATED CARBON

Activated carbon, when used for wastewater renovation, must be regenerated to make the process economically feasible. With granular carbon,

TABLE IV

Treatment of Primary Effluent by Powdered Carbon
Lebanon, Ohio

Run	Carbon (mg/1)	Flow (gpm)	Polymer (mg/1)		Primary Effluent		Powdered Carbon Effluent		Filter Run (hrs.)
			1st Stage	2nd Stage	TOC (mg/1)	Turbidity (JU)	TOC (mg/1)	Turbidity (JU)	
3	200	5	1.0	1.5	69.0	41.7	10.2	3.3	27
5	200	5	1.0	1.5	41.7	23.4	3.7	1.0	22
6	200	5	1.5	1.5	46.3	28.5	4.1	2.2	29
7	200	5	1.5	1.5	48.4	30.5	6.7	2.9	22
9	300	5	1.5	3.0	67.1	45.0	11.0	1.2	24

the cost of the carbon itself, if regeneration is not practiced, would be 11¢/1,000 gallons. In the case of powdered carbon, this cost would be about 15¢/1,000 gallons.

Under a contract with the Dow Chemical Company, FWPCA investigated chemical regeneration of spent granular carbon several years ago. The best regenerant of those tried was hydrogen peroxide which, on the first cycle, recovered 71% of the adsorptive capacity of the carbon. This fell off rapidly and the second and third cycles recovered 50 and < 20% respectively, of the adsorptive capacity (Johnson, Lowes, et al., 1964). The poor results achieved by chemical regeneration indicated that effort should concentrate on thermal regeneration, which had proved more successful.

The Pittsburgh Activated Carbon Company, under contract to the FWPCA, went through 15 exhaustion-regeneration cycles (Joyce and Sukenik, 1965). An externally heated laboratory furnace was used in an atmosphere consisting of 34% by volume steam and 66% air at a maximum temperature of 1740°F. During these cycles, the iodine number decreased from 942 to 782 units and the molasses number increased from 195 to 249 units. This indicates an increase in the number of pores with large diameter at the expense of the pores with small diameter. The total ash increased from 5.36 to 13.2%, most of this being acid soluble. Figure 8 (Joyce and Sukenik, 1965) shows a comparison of virgin carbon and carbon that had been regenerated 15 times. It is difficult to get a quantitative result from these data but the virgin carbon appears to have a greater capacity for COD removal.

The regeneration unit at Pomona is a 100 lb/hr, 6-hearth Herreshoff-type furnace. It has burners at the 4th, 5th, and 6th hearths and is operated at a maximum temperature of 1700°F. The fuel consumption is about 5,000 BTU/lb carbon and 0.5 to 1.0 lb steam/lb carbon is added. Figure 9 (Summary Report,

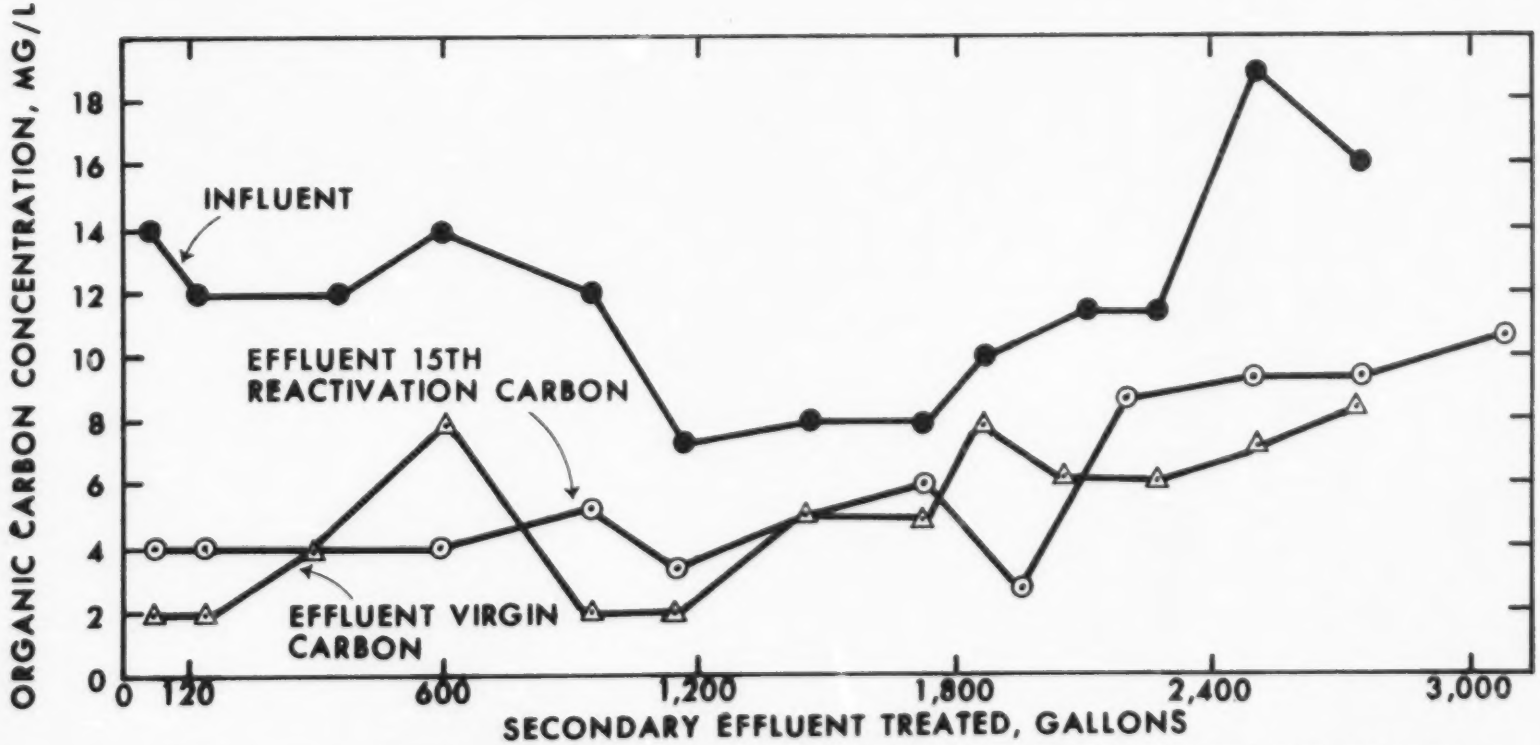

FIGURE 8 - ORGANIC CARBON REMOVAL PERFORMANCE OF VIRGIN SGL CARBON AND 15-CYCLE REACTIVATED CARBON.

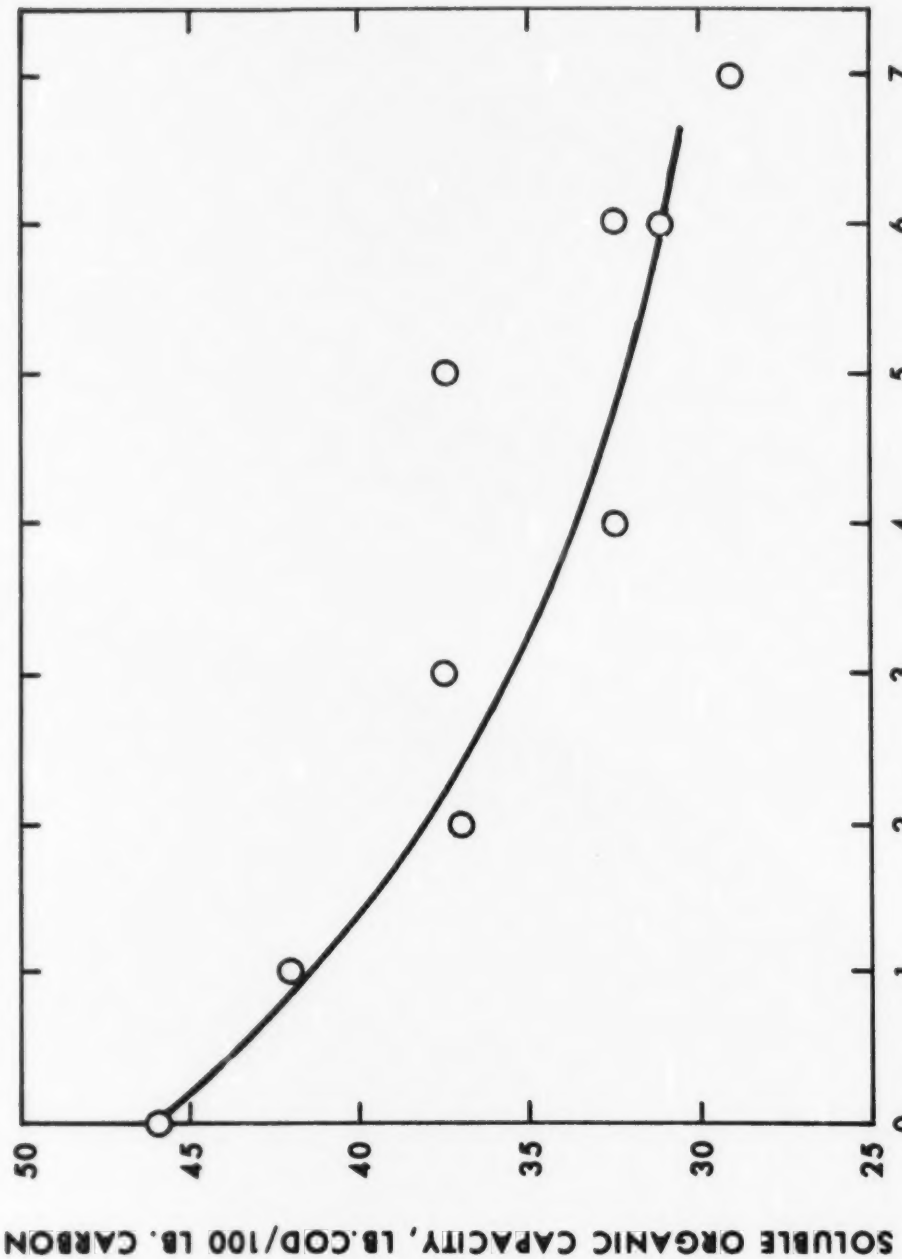

FIGURE 9 - EFFECT OF REACTIVATION ON ABSORPTION CAPACITY.

1968) is a plot of data taken from seven exhaustion-regeneration cycles on carbon from a 6 ft diameter column. During these seven cycles, the loading on the carbon, in lb dissolved COD/lb carbon, decreased from 0.46 to 0.29. During this same time period, however, the average dissolved COD content of the feed water decreased, accounting for part of the decreased loading.

The Mine Safety Appliances Research Corporation is making a detailed laboratory study of the conditions necessary to provide optimum recovery of capacity upon regeneration. Results to date indicate that regeneration efficiency can be improved significantly.

Much less is known about regenerating powdered carbon than granular carbon. Many plants in the sugar industry and several water treatment plants have switched from powdered to granular carbon because the former could not be regenerated without high losses. The main problem seems to be that the powdered carbon agglomerates and the transfer of heat into and out of these agglomerates is difficult.

Because the powdered carbon contacting process has promise, the FWPCA has sponsored research on three separate regeneration techniques designed to overcome the agglomeration problem. These studies are being conducted by Battelle Memorial Institute, FMC Corporation, and Dorr-Oliver, Inc. Laboratory work is essentially complete on the first two of these studies and the results are promising. The researchers have obtained virtually complete recovery of the carbon's capacity for adsorption and physical losses have been about 5%. The furnaces are being evaluated in actual service at the Lebanon pilot plant.

ECONOMICS

Several cost estimates have been made for large-scale granular carbon plants to treat wastewater. The contact time in these plants varied from 26 minutes to 48 minutes. Table V presents capital and operating cost estimates for four plants, three for treatment of secondary effluent and one (Rocky River) for treatment of primary effluent.

These cost estimates were not all made by the same organization and, therefore, different procedures were used for calculating items such as overhead, maintenance, and amortization. They are also for processes differing in configuration and objective and should not be compared with each other.

The Pittsburgh Activated Carbon Company estimate was made for a 2-stage downflow column configuration with a contact time of 48 minutes (Allen, Clapham, et al., 1964). The estimate for Lake Tahoe (Slechta, Culp, 1967) includes the cost of the separation beds that precede the carbon columns. The contact time is 18 minutes. The Pomona estimate is for a 4-stage downflow column with a contact time of 38 minutes. The Rocky River plant, as discussed before, will be eight columns in parallel with a contact time of 26 minutes. It includes $282,000 for a building to house the carbon columns and a cost of 3.8¢/1,000 gallons for chemicals to enhance primary treatment. The amortization schedule for the Pittsburgh-designed plant was 5%/year; for the Lake Tahoe and Rocky River Plants it was 7.358%/year (20 years, 4%); and for the Pomona plant it was 8.994% (15 years, 4%).

Figure 10 (Smith, 1968) presents the relationship between capital and operating costs and capacity of a carbon adsorption plant.

The Swindell-Dressler and W. M. Kellogg divisions of the Pullman Corporation are nearing completion on an FWPCA-sponsored study of the economics of wastewater treatment of granular carbon. Utilizing the

TABLE V

Capital and Operating Costs
Granular Carbon Adsorption

	Pittsburgh Activated Carbon Co.	Lake Tahoe	Pomona	Rocky River
Capacity, mgd	10	7.5	10	10
Investment ($1,000)	1,489	1,306	1,670	1,600
Operating Cost (¢/1000 gal.)				
Carbon	1.20	1.18	1.10	0.69
Fuel	0.11	--	0.25	0.12
Chemicals	--	0.99	--	3.80
Power	0.85	0.75	0.85	0.55
Labor	0.74	0.40	1.50	1.10
Overhead	0.27	--	--	--
Amortization	3.07 (20 yrs)	3.53 (20 yrs)	4.10 (15 yrs)	3.23 (20 yrs)
Maintenance	0.63	0.33	0.50	0.55
Total Operating Cost	6.87	7.18	8.30	10.04

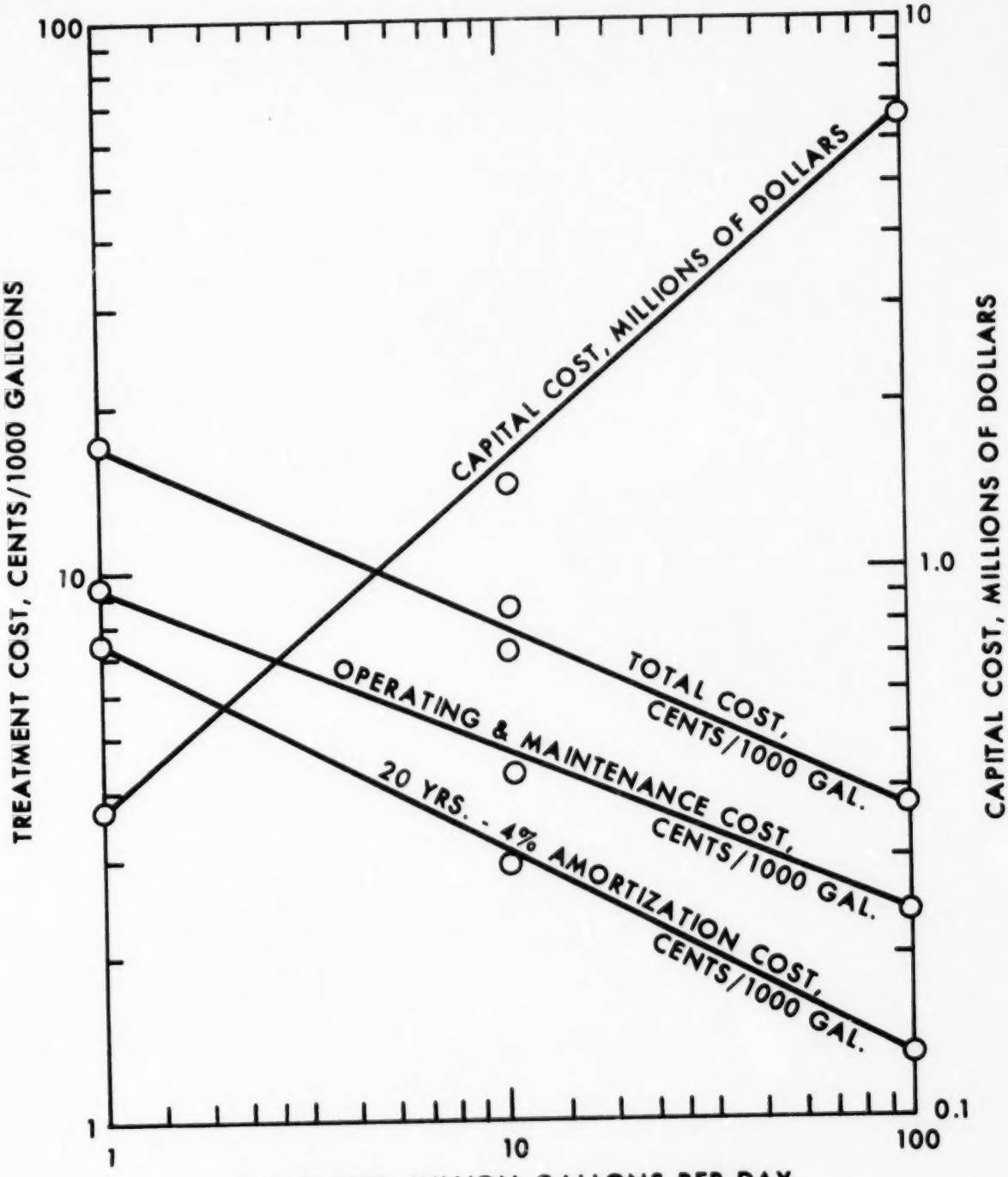

FIGURE 10 - COST ESTIMATES FOR GRANULAR CARBON ADSORPTION

information and experience available, they are calculating the economic effect of changing the many variables in the system. These variables, in part, include type of contactor (pressure or gravity flow), number of contactors, carbon capacity, regeneration rate, etc. Since much is yet to be learned about the carbon adsorption process, their report will not be the final definitive answer to the process but it should point up those areas in which research and development will be the most fruitful.

The costs for the powdered carbon adsorption process are estimated to be about the same as those for granular carbon. A firmer cost estimate can be made when more is known about regeneration of the spent powdered carbon.

CONCLUSION

Improvement of wastewater effluent quality by activated carbon adsorption, either granular or powdered, is a practical process that could be applied as needed today. Further research, development and application will undoubtedly bring improvements and economies but the present state of the art is such that efficient removal of organic contaminants from a secondary effluent can be assured at a reasonable cost. Within 2 to 3 years, technical and economic data should be available on a full-scale plant to allow evaluation of the use of activated carbon as a substitute for the biological processes.

Allen, J. B., Clapham, T. M., et al., "Use of Granular Regenerable Carbon for Treatment of Secondary Effluent - Engineering Design and Economic Development," Report to Public Health Service on Contract PH 86-63-243 (October 1, 1964).

Beebe, R. L., Stevens, J. I., "Activated Carbon System for Wastewater Renovation," pp. 43-5, Water and Wastes Engineering, 4, 1 (1967).

Davies, D. S., Kaplan, R. A., "Activated Carbon Eliminates Organics," pp. 46-50, Chemical Engineering Progress, 60, 12 (1964).

Johnson, R. L., Lowes, F. J., Jr., et al., "Evaluation of the Use of Activated Carbons and Chemical Regenerants in Treatment of Waste Water." Public Health Service Publication 999-WP-13 (1964).

Joyce, R. S., Sukenik, V. A., "Feasibility of Granular, Activated-Carbon Adsorption for Waste-Water Renovation, AWTR-10," Public Health Service Publication No. 999-WP-12 (1964).

Joyce, R. S., Sukenik, V. A., "Feasibility of Granular Activated-Carbon Adsorption for Waste-Water Renovation. 2. AWTR-15," Public Health Service Publication No. 999-WP-28 (1965).

Morris, J. C., Weber, W. J., Jr., "Adsorption of Biochemically Resistant Materials from Solution. 1. AWTR-9," Public Health Service Publication No. 999-WP-11 (1964).

Morris, J. C., Weber, W. J., Jr., "Adsorption of Biochemically Resistant Materials from Solution. 2. AWTR-16," Public Health Service Publication No. 999-WP-33 (1966).

Parkhurst, J. D., Dryden, F. C., et al., "Pomona Activated Carbon Plant," pp. R70-R81, Journal Water Pollution Control Federation, 39, Research Supplement (October 1967).

Rizzo, J. L., "Secondary Treatment with Granular Activated Carbon," Presented at the 42nd Annual Meeting of the Ohio Water Pollution Control Conference, Dayton, Ohio (June 21, 1968).

Slechta, A. F., Culp, G. L., "Water Reclamation Studies at the South Tahoe Public Utility District," pp. 787-814, Journal Water Pollution Control Federation, 39, 5 (May 1967).

Smith, R., "Cost of Conventional and Advanced Treatment of Wastewater," pp. 1546-74, Journal Water Pollution Control Federation, 40, 9 (Sept. 1968).

"Summary Report Advanced Waste Treatment - July, 1964 - July, 1967," U. S. Department of the Interior, Federal Water Pollution Control Administration, Publication WP-20-AWTR-19 (1968).